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(54) SMOKELESS FLARING OF COMBUSTIBLE GASES USING SUPER-CRITICAL VELOCITY STEAM

(71) We, JOHN ZINK COMPANY, of 4401 South Peoria, Tulsa, Oklahoma, United States of America; a corporation organised and existing under the laws of the State of Delaware, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The basic concept in this invention is significant enhancement of two of the "Three T's" which are fundamental for either combustion or chemical reaction, but specially related to smokeless flare burning. The "Three T's" are Turbulence, Temperature, and Time. Temperature and Turbulence determine Time for either burning or reaction since burning involves chemical reaction. The equations of Arrhenius relate to speed of reaction as a function of temperature. Turbulence, which is resultant from energy speeds temperature elevation and varies directly as the energy. In gaseous flow, energy resulting from such flow is $MV^2/2$, i.e., with constant mass, energy will vary as the square of the velocity thus velocity preservation up to a point of utilization enhances turbulence. With enhanced turbulence, reaction is speeded and if the reaction is exothermic (heat productive) temperature level is increased in reference to the speed-of-reaction increase.

As related to smokeless burning of flared hydrocarbons, the time factor is significant in avoiding smoke production because, if the slow-burning carbon (as a solid) can be held within a high-temperature zone long enough, there is complete burning of the carbon and avoidance of smoke production. In the arts of smoke suppression for burning hydrocarbons in flares, a number of chemical reactions are involved and they may be considered as:

1)—Direct oxidation of hydrocarbon
2)—Dissociation of hydrocarbons to H_2 and C (smoke productive)
3)—Water-gas shift reactions of C + H_2O
4)—Reformation of hydrocarbon with water-vapor to CO + H_2

These reactive conditions are either exothermic or endothermic. Where reaction is involved, greater turbulence or greater temperature speeds reaction, takes less time for complete reaction, and if the conditions of temperature/turbulence are right there is complete burning and avoidance of smoke since smoke (hydrocarbon) is a product of incomplete burning of hydrocarbons.

In the flare-burning of hydrocarbons the state of burning is in the open air at an elevated point, typically, where the potential for heat-loss in radiation, and in wind-rain cooling makes it imperative to establish the highest possible flame temperature within a very small fraction of a second after emergence of the hydrocarbon for burning. In the prior art, such as U.S. Patent Nos. 2,779,399 and 3,134,424, steam has been injected to the burning zone immediately downstream of the point at which the gases emerge for burning with the steam injection pressure typically 100 p.s.i. gauge (114.7 absolute). In the prior art there has not been proper utilization of the steam flow energy because the points from which the steam emerges, for directed travel into the burning zone, are considerably radially outward from the boundary of the hydrocarbon stream emerging for burning. Thus the streams must travel a significant distance before their turbulence potential can be realized and there is a great loss of energy *before* the energy is preferentially utilized.

In flow of gases from an orifice or port, and instantly upon emergence, the flowing gases possess latent kinetic energy which is velocity-established. The flow velocity is a function of the ratio of upstream absolute pressure to downstream absolute pressure. When the upstream pressure (absolute) is twice the downstream pressure (absolute)

the flow velocity for the gas becomes 'critical' or sonic, as it passes through the orifice restriction. Since the velocity as it passes through the orifice restriction, becomes 'critical' it is impossible to further accelerate the gas flow at that point. But if the ratio of absolute pressures exceeds 2 (as above) the flow becomes supersonic or supercritical downstream of the port or orifice because of a resultant increase in mass at critical velocity. This results in velocity increase as the additional mass or density (already at critical velocity) further expands. Examples of this are turbine-nozzles for steam and rocket nozzles for supersonic or supercritical energy utilization. A little appreciated fact is that the supercritical flow effect exists immediately downstream of any flow orifice or port. Due to the fact that in prior steam injection flare burning apparatus the supercritical expansion is not confined or directed, only part of the supercritical energy is useful in the directed area downstream of the orifice or port.

The radial location of the stream injection orifice or orifices as spaced from the border of flared gases is a critical factor as to energy delivery for turbulence as the flared gases subsequently burn. This factor is predicated on research-supported data that, in forward movement downstream of the orifice, substantially 90 of the orifice-stream energy will have been spent in a travel distance approximately equal to 9 orifice diameters (Master's Thesis, Fluid Flow, U. of Tulsa, Richard Martin). Thus if the orifice has a diameter of $\frac{3}{8}''$, within the forward gas movement of $3\frac{3}{8}''$, 90% of the gas stream energy will have been spent. Turbulence is proportional to energy and therefore, in this case, only 10% of the kinetic energy is useful. From this conclusion might be drawn that, in point of energy-turbulence potential, the orifice should be located immediately adjacent to the border of the gas stream and, if turbulence alone is considered, this is true. But since the end-purpose of turbulence is to promote reaction/temperature, the components for the preferred reaction/temperature must be present as the state of turbulence is created in order to promote rise in temperature.

In the case of steam injection alone, the potential reaction would be only the endothermic reforming condition and without adequate temperature level this reaction cannot occur to an appreciable degree. Therefore to cause generation of adequate heat the steam-stream must draw in air for the exothermic direct oxidation of hydrocarbon as the condition of turbulence exists. Thus it is preferable that: of the steam-stream energy, more nearly 50% be spent for turbulent energy and 50% spent for air induction. The steam orifice must be spaced radially outwardly from the border of the gas stream a limited distance to permit access of air to the vicinity of the issuing steam-stream where the pressure immediately adjacent to the orifice is less than 14.7 p.s.i. absolute. Preferred spacing radially outward from the border of the flared-gas stream is that spacing which will cause flow energy utilization in a preferred manner but there may be variation in gas flow boundary definition according to the flow characteristics of the device from which the flared gases flow.

In some cases, where the problem of smoke suppression is particularly demanding, it is desirable to cause steam-air injection in a flow direction which is horizontal, rather than in a direction which is above the horizontal in some angular relationship with the horizontal which is typical of the art of U.S. Patent Nos. 2,779,399 and 3,134,424.

It is a principal object of this invention to provide an apparatus for flaring combustible gases in which steam is utilized to provide highly turbulent mixing of the flare gas and air plus steam in order to get complete combustion of carbon.

According to the present invention there is provided an apparatus for the smokeless flaring of combustible gases, including means to flow said gases in a flare stack vertically upward to a tip of said stack to burn said gases at or above said tip; a plurality of steam injection nozzles peripherally adjacent said tip and directed toward said burning gases; and means to supply steam under pressure to said nozzles; wherein said nozzles include means to supply said steam therefrom at super-critical velocity, and said direction of flow of said steam from said nozzles is inwardly and upwardly above said tip into said burning gases and in which each said nozzle includes an insert which comprises a hollow cylinder having an inlet section, a float section and an expansion section.

The invention will be further illustrated by way of example, with reference to the accompanying drawings in which

Figures 1 and 2 show respective plan and partial sectional elevation views of the apparatus embodying this invention;

Figures 3A and 3B show two different types of steam nozzles which can be used to accomplish the objectives of this invention; and

Figures 4A, 4B and 4C illustrate the geometry of the positioning and directing the steam nozzles.

Referring to Figures 1 and 2 the numeral 10 indicates generally the flare stack tip construction while numeral 12 indicates generally the manifold and riser pipes that supply steam into the burning gases. The

flare stack is indicated generally as a vertical tubular column 16 to the top of which is attached a tip 18 by means of band or bracket 20 on the outside. This tip 18 has a plurality of circularly spaced orifices or openings 21 and 22 which are conventional.

A circular header pipe 24 is provided which surrounds the stack near its tip. This is a large diameter pipe and is supplied from a steam source via vertical supply pipe 25, also of large diameter so that under the flow conditions from the steam source (e.g. boiler) and the header 24 there is minimal pressure loss. Similarly, fairly large diameter vertical riser pipes 26 are provided angularly spaced around the header pipe 24. These rise vertically to a point above the tip of the flare stack and then are bent inward, at an angle to the vertical which is a function of the position of the tip of the nozzle radially outward from the flared gas stream and the vertical distance above the tip as will be explained in connection with Figures 4A, 4B and 4C.

Consider next Figures 3A and 3B. As has been discussed previously, the importance of conserving the pressure energy of the steam and converting it efficiently into supercritical steam discharge velocity at the outlet of the nozzle is extremely important in obtaining the maximum air injection and turbulence in the burning area. The ideal type of nozzle is show nin Figure 3A which includes an entry section 34, a throat section 36, and an expander section 38, which is slowly diverging or tapering outwardly from the throat section 36 leading to the outlet of the nozzle at 40.

Ideally the steam nozzle design is one in which the ratio of the upstream pressure P_1 to the downstream pressure P_2 (all pressures being absolute) is greater than two (2). As such, in the nozzle, the velocity flow in the area of the throat 36 is critical or sonic while in the confined expander section 38 the flow is one of added acceleration because of supplemental expansion downstream of 36 to achieve a directed supercritical flow velocity at P_2. This steam energy accomplishes the objects of drawing additional combustion air into the burning flare and creates therewith turbulence and mixing for more efficient smokeless combustion. The expanding included angle of the expansion section of the nozzle 38 is generally an angle of 7 to 14°.

It has been found that in place of the nozzle shown in Figure 3A, which when properly designed is the most efficient, a very satisfactory substitute for that nozzle is shown in Figure 3B. This comprises a cylindrical block of metal 42 in which is bored an axial opening 44 at one end 43 and an axial opening 48 at the outlet end 47 of larger diameter. The opening 44 corresponds to the throat 36 of the nozzle of Figure 3A and the expansion section corresponds to the larger diameter portion 48. The diameter of the neck puortion is D, and the corresponding length is indicated at X. The expansion section is indicated of length Z and its diameter is indicated as Y.

Each of the dimensions X, Y and Z can have a limited range for optimum conditions. For example, X can be in the range of 0.5D to 2D. Y can be in the range of 1.05D to 1.50D and Z can be in the range of 0.2D to 1.3D, preferably 0.2D to 0.60D.

The position of the nozzle with respect to the column of gas is very important. On the consideration of velocity alone the nozzle should be close to the column of gas so that the velocity of the steam will carry into the column of rising gas. On the other hand, the nozzle should be out far enough to entrain some air with the steam to provide for combustion. Also, the nozzle should be positioned downstream of the tip of the flare to give the gas some opportunity to partially burn and provide heat to the mixture. Entry of steam and consequent reforming is a cooling reaction.

However, there is some latitude in the position of the nozzle, although the relation between spacings and angle are very important. When the nozzle outlet is placed close to the gas stream, say a distance outward of D where D is the diameter of the nozzle, i.e. of the throat section, the angle from the horizontal of the nozzle should be in the range of 50° to 80° and the nozzle placed a short distance, preferably about one inch above the tip edge of the flare 60. This is illustrated in Figure 4A where the numeral 60 indicates the flare tip and 62 illustrates the rising column of flare gas and the point 64 indicates the position of the outlet of the steam nozzle. As shown in Figure 4B, if the nozzle is moved radially outwardly to a distance 2D then the nozzle should be raised to a position such as 3″ above the flare tip, and the angle of the nozzle lowered to the range of 30° to 45°. Going still farther outward to a distance, say 4D, the point 64 or the position of the outlet of the nozzle should be raised a distance such as 4″, and the angle of the nozzle lowered to the range of 20° to 30°. This relationship of angle and position of the nozzle has been determined in its relation to providing a maximum of combustion air and a maximum turbulence for the combustion of the gas. Factors of anticipated maximum wind velocity and the nature of the flare stack must be considered.

Summarizing the embodiment of this invention, it comprises a plurality of steam nozzles designed in accordance with the nozzles of Figure 3A or 3B and positioned

in accordance with the dimensions and ranges of angle of Figures 4A, 4B and 4C and supplied with steam through large diameter riser and manifold pipes so that there is a minimum reduction of steam pressure between the steam supply or boiler and the nozzles so that the boiler pressure can be utilized to greater efficiency in providing high velocity steam jets to cause extreme turbulence in mixing and smokeless combustion of the flare gases.

While the invention has been described with a certain degree of particularity it is manifest that many changes may be made in the details of construction and the arrangement of components. It is understood that the invention is not to be limited to the specific embodiment set forth herein by way of exemplifying the invention but the invention is to be limited only by the scope of the attached claims.

WHAT WE CLAIM IS:—

1. An apparatus for the smokeless flaring of combustible gases, including means to flow said gases in a flare stack, vertically upward to a tip of said stack, to burn said gases at or above said tip; a plurality of steam injection nozzles peripherally adjacent said tip and directed toward said burning gases; and means to supply steam under pressure to said nozzles; wherein said nozzles include means to supply said steam therefrom at super-critical velocity, and said direction of flow of said steam from said nozzles is inwardly and upwardly above said tip into said burning gases and in which each said nozzle includes an insert which comprises a hollow cylinder having an inlet section, a throat section and an expansion section.

2. An apparatus as claimed in claim 1 in which, in each nozzle, said expansion section diverges from said throat section to define an included angle of 7° to 14°.

3. An apparatus as claimed in claim 1 or 2 in which the throat section of each said nozzle is of diameter D, has a length in the range of 0.5D to 2D, and the expansion section is of diameter in the range of 1.05D to 1.5D and of length in the range of 0.2D to 0.6D.

4. An apparatus as claimed in claims 1, 2 or 3 in which the outlet of each of said nozzles is positioned radially outward from the circumference of the rising gas stream a distance D, where D is the diameter of the throat section of each said nozzles, and approximately 1 inch above the tip of the flare and the nozzle axis is at an angle of 50° to 80° above the horizontal.

5. An apparatus as claimed in claim 1, 2 or 3 in which the outlet of each of said nozzles is positioned radially outward from the circumference of the rising gas stream a distance 2D, where D is the diameter of the throat section of said nozzles, and approximately 3 inches above the tip of the flare, and the nozzle axis is at an angle of 30° to 45° above the horizontal.

6. An apparatus as claimed in claim 1, 2 or 3 in which the outlet of each of said nozzles is positioned radially outward from the circumference of the rising gas stream a distance 4D, where D is the diameter of the throat section of said nozzles, and approximately 4 inches above the tip of the flare and the nozzle axis is at an angle of 20° to 30° above the horizontal.

7. An apparatus for the smokeless flaring of combustion gases, substantially as herein before described with reference to and as illustrated in the accompanying drawings.

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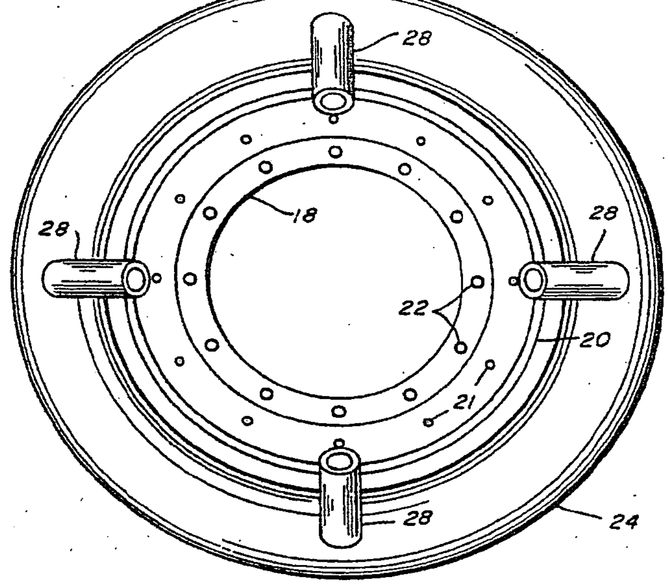

FIG. 1

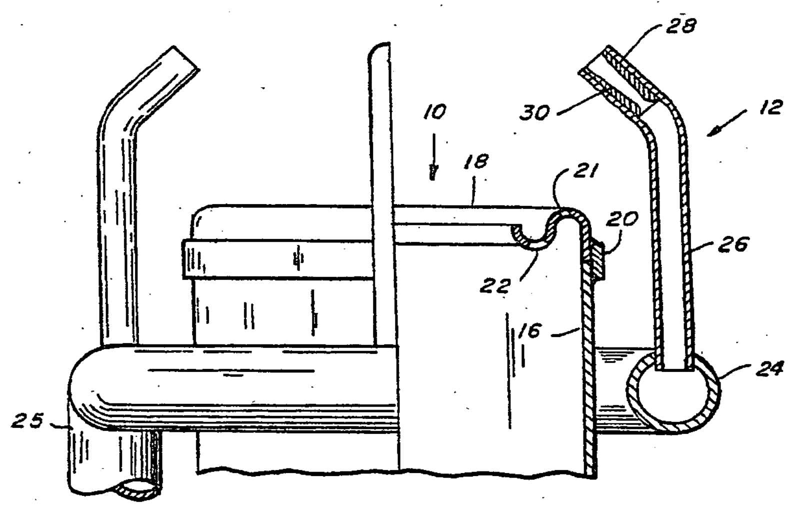

FIG. 2

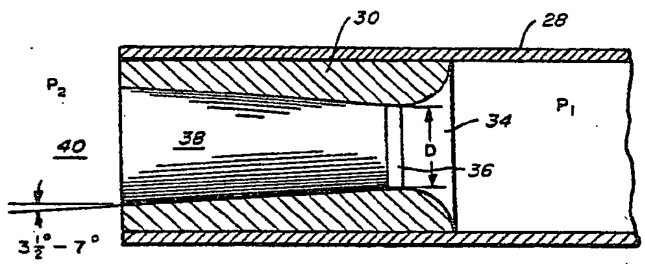

FIG. 3A

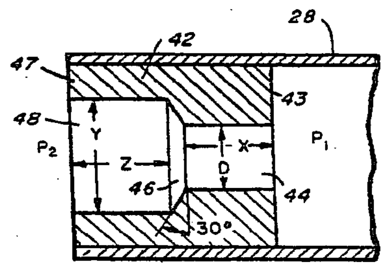

FIG. 3B

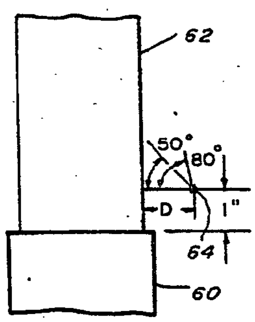

FIG. 4A

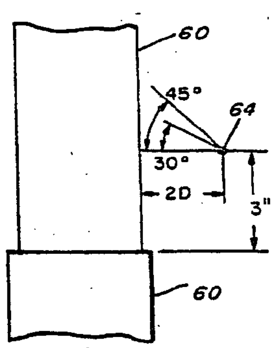

FIG. 4B

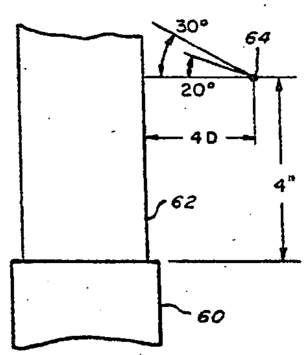

FIG. 4C